

supplementary

Glossary of terms used in electronics: D

Click on the first letter of the term that you require



dash number Method for using part numbers to identify and control design modifications and interchangeability of assemblies. Using a root part number with different dash numbers indicates that variations of the same functional design exist.

data file A collection of information organized in a specific manner for a specific application.

database A collection of interrelated data items stored together without unnecessary redundancy, to serve one or more applications.

datum The theoretical exact point, axis, or plane from which the location of geometric characteristics or features of a part are dimensionally established. Whence **datum intersection (origin)** The point of intersection of the X and Y datums on a circuit board and the origin (0,0 point) of the layout grid. The 0, 0 point of a layout grid, usually located in the lower left corner of a board.

daughter board A PCA attached to a mother board to provide additional and/or alternate electrical functions and capabilities.

DCA = Direct Chip Attach See Chip-On-Board.

decals A graphic software representation of a component, so named because hand tape-up of printed circuit boards employed the use of pull-off and paste decals to represent components. Also called a part, footprint or package. On a manufactured board the body of a footprint is an epoxy-ink outline.

decoupling capacitor See bypass capacitor.

dedicated service product Equipment or system that must perform reliably over long periods of time and experience minimum downtime, such as communication equipment, computers, and online instrumentation.

DEFRA: Department for Environment, Food and Rural Affairs

delamination A separation between plies within the base material, between the base material and the conductive foil, or both. Occurs both in PCBs and chip ceramic capacitors.

dendritic growth Metallic filament growth between conductors in the presence of condensed moisture and electrical bias, threatening an electrical short. (Also known as 'whiskers')

derating Use of materials or components in a design at less than their rated characteristics (such as power dissipation or current-carrying capacity) to enhance the long-term reliability of the end product. Part manufacturers usually specify a derating factor to be used when a part is to be operated above a certain temperature.

design cycle The entire technical activity associated with the design fabrication, assembly, test, and integration of a PCA

Design for Manufacture (Manufacturability) (DfM) Designing a product to be produced in the most efficient manner possible in terms of time, cost and resources, taking into consideration how the product will be processed, and using the existing skill base to achieve the highest yields possible.

design qualification Verification through test and analysis that a PCA design will perform its required operational functions.

design reviews Checkpoints established at critical points in the design process to verify the validity of the design and its associated data and documentation, and evaluate the producibility, testability, and projected reliability of the product.

design rules A set of layout guidelines which is used to ensure that designs meet the criteria of electronic circuit performance, ease of board fabrication and yield/cost at assembly, test and rework. Typically these rules will establish minimum dimensions and spacing, and contain recommendations on good practice. Be aware that the design rules applied by board fabricators and assemblers will vary between different companies.

design standards Layout processes, guidelines, and procedures that are widely used throughout the industry.

desoldering methods Disassembling solder parts to repair or replace by wicking, sucking, heat and pull, or solder extraction.

dewetting A condition that occurs when molten solder has coated a surface and then receded, leaving irregularly shaped mounds of solder separated by areas covered with a thin solder film. Voids may also be seen in the dewetted areas. Dewetting is difficult to identify since solder may be wetted at some locations and base metal exposed at others. Depending on the location, may be caused by excessive heating, inadequate cleaning or over-oxidation of the attachment area.

diametral Pertaining to the diameter of a circle or hole.

die A single rectangular piece of semiconductor material onto which specific electrical circuits have been fabricated. Refers to a semiconductor which has not yet been packaged.

dielectric An insulating medium which occupies the region between two conductors.

dielectric material A insulating material: one that conducts no current when voltage is applied across it.

dielectric constant A property that is a measure of the ability of an insulating medium to store electrostatic energy. Numerically, the dielectric constant of an insulating material is the ratio of the capacitance value when using the material, to the capacitance value of the same geometry (area and thickness) component but using vacuum as an insulator.

differential pair Conductors carrying sensitive signals that should generally be routed in parallel with matched overall lengths.

digital Indicates the representation of data by a series of bits or discrete values, such as 0s and 1s.

digital clock lines Conductors that carry a continuous stream of uniform pulses (0s and 1s)

that establish the timing of operation of associated digital circuitry.

digital signal processor An integrated circuit that electronically processes signals such as sound, radio, and microwaves by converting them from analogue to digital signals.

digitising A method of capturing the X-Y coordinates of feature locations on a PCA layout and converting that data to a digital format.

dimensional origin See datum intersection (origin).

dimensional tolerance The total amount that a specific dimension is permitted to vary. The tolerance defines the maximum and minimum limits of the dimension.

DIP = Dual In-line Package An integrated circuit package that has two rows of pins or lead-wires for through-hole mounting positioned along opposing long sides of the package. The number of leads and the spacings between leads and between rows are all standardised, the most common spacing being 2.54mm (0.1in) between centres of adjacent pins.

dip soldering A process whereby printed boards are brought in contact with the surface of a static pool of molten solder for the purpose of soldering the entire exposed conductive pattern and component leads in one operation.

discrete wire A single cable or wire, to be terminated on to a connector contact.

dispensing (syringe) Application of adhesives by pressurized (hydraulic or pneumatic) force for a specific period required to emit an 'appropriate' amount of material through the needle and onto the target location.

dispersant A chemical additive to water to improve particulate removability.

dissipation factor A measure of the absorption of electromagnetic energy passing through a dielectric material.

disturbed connection A soldered connection where there is movement between the metal surfaces during solder solidification. The connection can have a dull, granular, rough, lumpy appearance and may have noticeable spiral cracks or a separation of the component lead from the solder fillet. The joint will also be of lower than average mechanical strength. Also referred to as 'disturbed joint'.

documentation Information for a PCB that explains the electromechanical design concept, types and quantities of parts and materials, special instructions, and revisions. Will include a Bill of Materials.

documentation/data release The activity that takes place following final review and approval (signoff), when all drawings and design data are placed into a configuration/records control system.

dolls To-scale cut-outs that represent physical parts to be mounted on a circuit board. They are used to perform component placement during a manual layout effort.

doping The introduction of an impurity into a semiconductor to modify its electrical properties.

DOS = Disk Operating System A program that controls the computer's transfer of data to and from a hard or floppy disk. Personal computers that are IBM-compatible run DOS rather than other early varieties of operating systems.

DOS-formatted (of magnetic data storage media, such as floppy disks.) Prepared for storage of data in such a way that DOS transfer can occur.

double-sided (board) A printed board with a conductive pattern on both sides of the board.

double-track Slang for fine line design with two traces between DIP pins.

DRAM = Dynamic Random Access Memory. A type of memory component. 'Dynamic' means that the device's memory cells need to be periodically recharged. Information stored in the memory cells, as a positive or negative charge, can be accessed randomly.

draw or flash A designation assigned to a photoplotting aperture. A flash aperture is the size and shape of the feature it defines on photosensitive film; a draw aperture creates the shape on film via software move commands transmitted to a photoplotter.

drawbridging A variant of tombstoning in which the component is at a small angle to the substrate rather than almost at right-angles.

drawing Documentation that provides the configuration and requirements information needed to build a product.

drill data Information that specifies X-Y locations for all drilled holes, their sizes, and their plating requirements.

drill spindle run-out The undesirable deviation from the theoretical centre of rotation of a drill spindle due to its inherent mechanical tolerances.

drill-out A method used to modify a fabricated circuit board or assembly by drilling through a conductor (usually internal) or plated hole to break the connection.

driver A signal source that generates an output strong enough to change logic levels of all devices (loads) attached to its net.

dross Oxide and other contaminants which form on the surface of molten solder.

dry film material A photosensitive resist or solder mask material available as a film (as opposed to a liquid) that is applied to a circuit board during fabrication, using heat and pressure. Dry film solder mask can manage the higher resolution required for fine line design and surface mount, but is more expensive than liquid photoimageable solder mask.

dual solder wave A wave soldering process in which an initial 'wave' of molten solder covers all PCB surfaces contacted. It is followed by a second laminar or 'flat' wave that serves to 'finish' the board by removing all solder bridges and icicles.

dummy traces Added non-functional conductors that help achieve plating balance. See thieves.

DUT = Device Under Test Used to describe both the unit being tested and an interface board placed between the device and the computerised test equipment.

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Dielectric

From Wikipedia, the free encyclopedia

A **dielectric** is a nonconducting substance, i.e. an insulator. The term was coined by William Whewell in response to a request from Michael Faraday.^[1] Although "dielectric" and "insulator" are generally considered synonymous, the term "dielectric" is more often used when considering the effect of alternating electric fields on the substance while "insulator" is more often used when the material is being used to withstand a high electric field. Von Hippel, in his seminal book, takes this definition further, stating:

Dielectrics... are not a narrow class of so-called insulators, but the broad expanse of *nonmetals* considered from the standpoint of their interaction with electric, magnetic, or electromagnetic fields. Thus we are concerned with gases as well as with liquids and solids, and with the storage of electric and magnetic energy as well as its dissipation.^[2]

Dielectrics is the study of dielectric materials and involves physical models to describe how an electric field behaves inside a material. It is characterized by how an electric field interacts with an atom and is therefore possible to approach from either a classical interpretation or a quantum one.

Many phenomena in electronics, solid state and optical physics can be described using the underlying assumptions of the dielectric model. This can mean that the same mathematical objects can go by many different names.

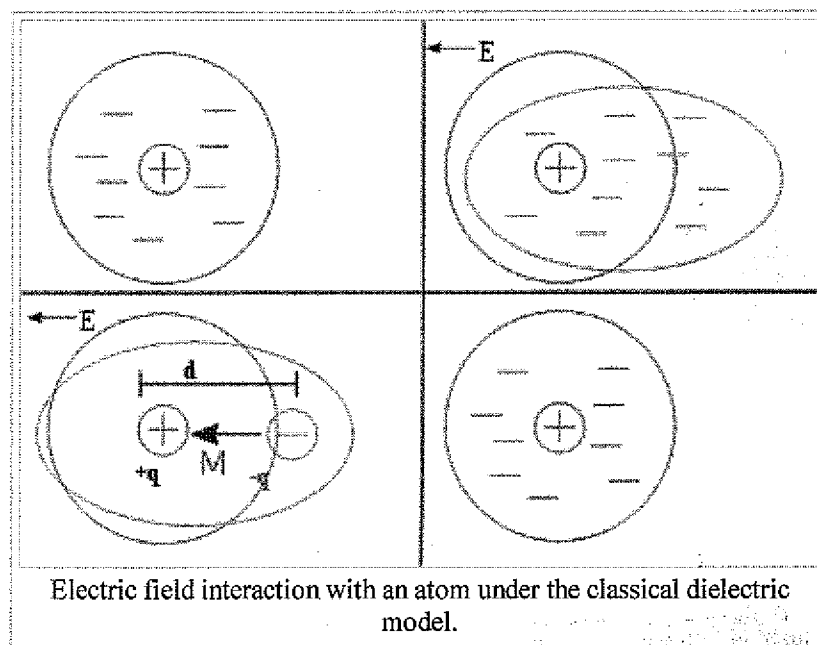
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Definitions

Classical

In the classical approach to the dielectric model, a material is made up of atoms. Each atom consists of a cloud of negative charge bound to and surrounding a positive point charge at its centre. Because of the comparatively huge distance between them, none of the atoms in the dielectric material interact with one another. *Note: Remember that the model is not attempting to say anything about the structure of matter. It is only trying to describe the interaction between an electric field and matter.*



In the presence of an electric field the charge cloud is distorted, as shown in the top right of the figure.

This can be reduced to a simple dipole using the superposition principle. A dipole is characterized by its dipole moment, a vector quantity shown in the figure as the blue arrow labeled M . It is the relationship between the electric field and the dipole moment that gives rise to the behavior of the dielectric. *Note: The dipole moment is shown to be pointing in the same direction as the electric field. This isn't always correct, and it is a major simplification, but it is suitable for many materials.*

When the electric field is removed the atom returns to its original state. The time required to do so is the so-called relaxation time; an exponential decay.

Behavior

This is the essence of the model. The behavior of the dielectric now depends on the situation. The more complicated the situation the more rich the model has to be in order to accurately describe the behavior. Important questions are:

- Is the electric field constant or does it vary with time?
 - If the electric field does vary, does it vary quickly or slowly?
- What are the characteristics of the material?
 - Is the direction of the field important (isotropy)?
 - Is the material the same all the way through (homogeneous)?
 - Are there any boundaries/interfaces that have to be taken into account?
- Is the system linear or do nonlinearities have to be taken into account?

The relationship between the electric field E and the dipole moment M gives rise to the behavior of the dielectric, which, for a given material, can be characterized by the function F defined by the equation:

$$M = F(E).$$

When both the type of electric field and the type of material have been defined, one then chooses the simplest function F that correctly predicts the phenomena of interest. Examples of possible phenomena:

- Refractive index
- Group velocity dispersion
- Birefringence
- Self-focusing
- Harmonic generation

May be modeled by choosing a suitable function F .

Dielectric model applied to vacuum

From the definition it might seem strange to apply the dielectric model to a vacuum, however, it is both the simplest and the most accurate example of a dielectric.

Recall that the property which defines how a dielectric behaves is the relationship between the applied electric field and the induced dipole moment. For a vacuum the relationship is a real constant number. This constant is called the permittivity of free space, ϵ_0 .

Applications

Capacitors

Commercially manufactured capacitors typically use a solid dielectric material with high permittivity as the intervening medium between the stored positive and negative charges. This material is often referred to in technical contexts as the "capacitor dielectric" [3]. The most obvious advantage to using such a dielectric material is that it prevents the conducting plates on which the charges are stored from coming into direct electrical contact. More significantly however, a high permittivity allows a greater charge to be stored at a given voltage. This can be seen by treating the case of a linear dielectric with permittivity ϵ and thickness d between two conducting plates with uniform charge density σ_ϵ . In this case, the charge density is given by

$$\sigma_\epsilon = \epsilon \frac{V}{d}$$

and the capacitance per unit area by

$$C = \frac{\sigma_\epsilon}{V} = \frac{\epsilon}{d}$$

From this, it can easily be seen that a larger ϵ leads to greater charge stored and thus greater capacitance.

Dielectric materials used for capacitors are also chosen such that they are resistant to ionization. This allows the capacitor to operate at higher voltages before the insulating dielectric ionizes and begins to allow undesirable current flow.

Cable insulation

The term "dielectric" may also refer to the insulation used in power and RF cables. Common materials used as electrical insulations are electrical insulation paper and plastics.

Some practical dielectrics

Dielectric materials can be solids, liquids, or gases. In addition, a high vacuum can also be a useful, lossless dielectric even though its relative dielectric constant is only unity.

Solid dielectrics are perhaps the most commonly used dielectrics in electrical engineering, and many solids are very good insulators. Some examples include porcelain, glass, and most plastics. Air, nitrogen and sulfur hexafluoride are the three most commonly used gaseous dielectrics.

- Industrial coatings such as parylene provide a dielectric barrier between the substrate and its environment.
- Mineral oil is used extensively inside electrical transformers as a fluid dielectric and to assist in cooling. Dielectric fluids with higher dielectric constants, such as electrical grade castor oil, are often used in high voltage capacitors to help prevent corona discharge and increase capacitance.
- Because dielectrics resist the flow of electricity, the surface of a dielectric may retain *stranded* excess electrical charges. This may occur accidentally when the dielectric is rubbed (the triboelectric effect). This can be useful, as in a Van de Graaff generator or electrophorus, or it can be potentially destructive as in the case of electrostatic discharge.
- Specially processed dielectrics, called electrets (also known as ferroelectrics), may retain excess internal charge or "frozen in" polarization. Electrets have a semipermanent external electric field, and are the electrostatic equivalent to magnets. Electrets have numerous practical applications in the home and industry.
- Some dielectrics can generate a potential difference when subjected to mechanical stress, or change physical shape if an external voltage is applied across the material. This property is called piezoelectricity. Piezoelectric materials are another class of very useful dielectrics.
- Some ionic crystals and polymer dielectrics exhibit a spontaneous dipole moment which can be reversed by an externally applied electric field. This behavior is called the ferroelectric effect. These materials are analogous to the way ferromagnetic materials behave within an externally applied magnetic field. Ferroelectric materials often have very high dielectric constants, making them quite useful for capacitors.

See also

- | | | | |
|------------------------|------------------------------|--|---------------------|
| ■ capacitor | ■ spectroscopy | ■ permittivity | ■ piezoelectricity |
| ■ dielectric strength | ■ electric susceptibility | ■ dielectric constant of vacuum (ϵ_0) | ■ RC delay |
| ■ dielectric constant | ■ electrorotation | ■ high-k | ■ ferroelectric |
| ■ dielectric resonator | ■ rotational brownian motion | ■ leakage | ■ QBD (electronics) |
| ■ dielectric | ■ low-k | ■ electret | |

References

1. ^ J. Daintith, "Biographical Encyclopedia of Scientists" CRC Press, 1994, ISBN 0750302879, page 943
2. ^ A. R. Von Hippel (ed), "Dielectric Materials and Applications", published jointly by the Technology Press of MIT and John Wiley, NY, 1954
3. ^ States7113388 United States patent 7113388, "*Semiconductor capacitor with praseodymium oxide as dielectric*", granted 2004-10-18, assigned to IHP GmbH- Innovations for High Performance Microelectronics/Institute Fur Innovative Mikroelektronik

External links

- Electromagnetism (http://www.lightandmatter.com/html_books/0sn/ch11/ch11.html) - A chapter from an online textbook
- Dielectric Sphere in an Electric Field (http://wiki.4hv.org/index.php/Dielectric_Sphere_in_Electric_Field)

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[di'elek'trik]

1 *adj.* transmitting electric effects by induction, but not by conduction. The term is applied to an insulating substance through or across which electric force is acting or may act by induction without conduction.

2 *n.* an insulating substance that transmits in this way, i.e., through or across which electric force is acting or may act by induction without conduction.

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dielectric

said of an insulating substance through which an electric force acts by induction but not conduction.

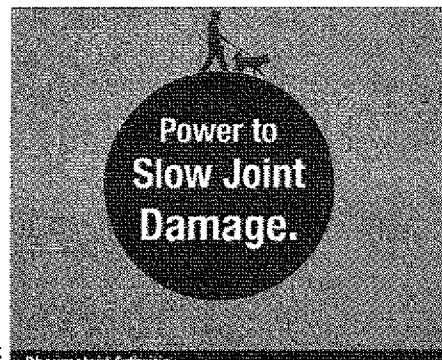
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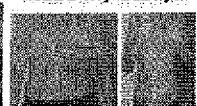
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Electrets are produced by heating certain **dielectric materials** to a high temperature and then letting them cool while immersed in a strong electric field.

[It's easily fooled by PS, the Preventive Maintenance Monthly](#)

Two new **dielectric materials** have been developed to meet the needs for improved via and signal trace density, improved electrical performance and reduced cost.

[A new, thin high-performance organic substrate: the flip-chip package ... by Qu. Shichun / Circuits Assembly](#)

Dielectric materials can be made to hold an electrostatic charge, but current cannot flow through them.

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Definition of dielectric

1 : a nonconductive material; an insulator. Examples are silicon dioxide and silicon nitride.

[SEMATECH] 2 : a material applied to the surface of a ceramic or preformed plastic package to provide functions such as electrical insulation, passivation of underlying metallization, and limitations to solder flow. [SEMI G33-90]

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Thermal Products Glossary

Alpha (α)

The sensitivity of a thermistor to change its resistance in response to a change in temperature. The units are ohms per Ohm per °C but usually written as % change per °C. Also called temperature coefficient.

Ambient

The normal or typical environmental temperature for the product or area. For example, the typical ambient room temperature may be 20 °C.

Automatic Reset

A type of thermostat that will automatically reset at a specific temperature (i.e., thermostat opens: 60 °C and closes or "resets" itself at 50°C).

Axial Leads

Leads of an electronic component that point in opposite directions resembling an axle.

Beta (β)

A constant used in a mathematical expression relating resistance to absolute temperature. Not suitable over a wide temperature range as Beta itself varies with temperature. Honeywell uses 0 °C and 50 °C to calculate Beta.

Bi-Metal

Two dissimilar metals molecularly bonded together to form the material for the manufacture of snap discs that actuate the Honeywell line of thermostats.

Bridge

A simple resistor network for comparing the resistance of an unknown component to that of a standard resistor. Also known as a Wheatstone bridge.

Ceramic

A non-metallic material able to withstand high temperature without degradation. A hard, dense material derived from mixing metal oxides and firing in a high temperature furnace.

Chip

A thermistor configuration derived from cutting out small pieces from a much larger flat square thermistor billet.

Close On Rise (COR)

COR refers to the operation of the contacts. When the temperature rises to its set point the contacts close or make contact which completes the circuit.

Coefficient

A multiplier of a term in a formula.

Constant

A fixed value in a formula.

Dielectric Material

A non-conductive, insulating material that separates the current carrying area from the application in both thermostats and heaters.

Differential

Sometimes called hysteresis.

Disc

A thermistor configuration in the shape of a pill.

Discrete

A thermistor without a housing.

Dissipation Constant (D.C.)

The amount of power required to raise to lower the temperature of an electronic component by one Celsius degree. The units are watts or milliwatts/°C.

Glass Bead

A thermistor configuration consisting of a small bead of thermistor material with two imbedded platinum wires with a glass coating.

Glass Encapsulated Chip

A chip thermistor in an axial lead package configuration utilizing glass diode technology.

Glass Probe

A bead thermistor encapsulated in a long glass sleeve and utilizing dumet lead wire extensions.

Hermetic

Refers to a device that is sealed by either metal to metal or glass to metal fusion to prevent moisture or contaminants from entering the switch cavity. The degree of seal is numerically expressed in the form of a maximum allowable leak rate.

Example: 1×10^{-8} ATM cc/s

ICL™

Inrush Current Limiter. A class of power handling thermistors intended to restrict the initial turn on current when placed in series with such components as tungsten filament light bulbs or between the rectifiers and the filter capacitor in a dc power supply.

Iso-Chip™

Honeywell's trade name for chip thermistors.

Iso-Curve™

Honeywell's trade name for interchangeable glass bead or glass probe thermistors. Accomplished by selecting parts of thermistors so that their combined resistance precisely match an established resistance temperature curve over a specified temperature range.

Interchangeability

The maximum indicated change in temperature when substituting thermistors.

Linearity

Ability to closely follow a straight-line resistance temperature function.

LTN®

Linear thermistor network. A combination of series/parallel fixed resistor(s) and thermistor(s) to produce a straight-line resistance temperature function over a specified temperature range.

Manual Reset

A bi-metal thermostat with a wide differential and a reset button which must be pressed to return the contacts to a closed position (Available in open on rise configurations only).

Maximum Differential

The maximum number of degrees between the actual open and closing set points.

Micro-Mini Chips

A small fast response interchangeable thermistor chip. It is encapsulated in a sleeve with a maximum diameter of 0.020 in. Often used in medical electronics.

Minimum Differential

The minimum number of degrees between the actual open and closing set points (also called deadband).

Nominal Differential

The number of degrees between the nominal set points regardless of tolerance.

NTC

Negative Temperature Coefficient. Refers to the negative slope or decreasing resistance of a thermistor with increasing temperature.

Ohm (Ω)

Unit of resistance.

Open On Rise (OOR)

OOR refers to the opening of the contacts when the temperature rises to the set point causing an interruption of the circuit.

Phenolic

The thermo-set plastic used as the insulating body of the thermostat; it has a UL rated temperature of $177\text{ }^{\circ}\text{C} \pm$ and a comparative strength value of 30,000 lb at ambient. This material will not melt, however, it will deteriorate at high temperatures.

Posi-Chip™

A type of resistive temperature sensor comprised of a chip of bulk silicon with a positive slope.

Probe Assembly

A finished thermistor assembly complete with thermistor housing, extension leads and sometimes a connector.

R-T Curve

Resistance versus temperature table or graph of a thermistor.

Radial Leads

Leads of an electronic component that exit the body on a line from the center out to the edge. The leads continue outward parallel to each other.

Ratio, 0 to 50

The dividend of dividing the resistance of a thermistor at $0\text{ }^{\circ}\text{C}$ by its resistance at $50\text{ }^{\circ}\text{C}$. Indicative of slope and useful for comparison purposes.

Resistance

The characteristic of an electrical device that provides opposition to the flow of current.

Resistance Deviation

Additional tolerance due to slope variations in comparison to a specified nominal resistance temperature curve.

Resistivity

The property of the bulk resistance of materials when reduced to a standard unit shape. The standard shape is taken as a 1 cm cube and the units of measurement are Ohm-cm. Useful in predicting the actual resistance of a thermistor when the resistivity is known along with its dimensions.

Response Time

The time for a thermistor to indicate a step change in temperature to within a specified amount.

Ro

The resistance of a thermistor at zero power at a specified temperature.

Self Heat

Temperature rise due to power dissipated within itself.

Slope

The steepness of a resistance temperature curve at a specified temperature. Usually given as ohms change per degree Celsius or percent change per degree which is also known as Alpha (α).

S.P.S.T. (Single Pole/Single Throw)

An electrical switch with one set of terminals and one set of contacts that will actuate or terminate a circuit.

Thermistor (Thermal Resistor)

A ceramic temperature sensitive resistor.

Time Constant (T.C.)

The time required for a thermistor to indicate 63 % of a step change in temperature.

Tolerance

The allowable range above and/or below the nominal operating temperature.

Uni-Curve®

An interchangeable chip thermistor.

Watts

A measure of power consumed or dissipated by an electrical component.

GROUP IVA

GROUP IVA

...

CARBON

...

SILICON

...

GERMANIUM

...

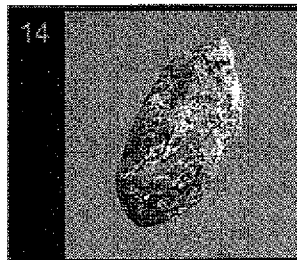
TIN

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LEAD

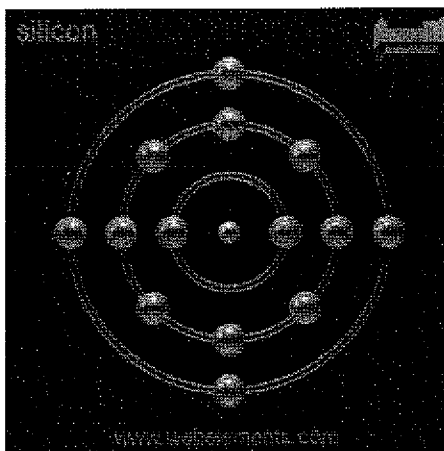
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SILICON



THE BASICS

- Name: Silicon
- Atomic Number: 14
- Chemical Symbol: Si
- Electronic Configuration: $1s^2 2s^2 2p^6 3s^2 3p^2$



- Abundance:
 - Earth: 2.77×10^5 ppm
 - Solar System: 4.47×10^7 (rel. to [H]) $= 1 \times 10^{12}$
- Atomic Mass: 28.0855
- Electronegativity:
 - Pauling: 1.9
 - Allred: 1.74
 - Absolute: 4.77 eV
- Electron Affinity: $133.6 \text{ kJ mol}^{-1}$
- Polarizability: 5.4 \AA^3
- Radius:
 - Si^{4+} : 26 pm
 - Atomic: 117 pm
 - Covalent: 117 pm
 - Van der Waals: 200 pm
 - Si^{4-} : 271 pm
- Common Ions : Si^{4+} , Si^{4-}
- Most Common Elementary Substance : Si
- Elementary Substance Class : Semi-metal

- **Origin** : Natural
- **Physical State** : Solid
- **Density [298K]** : 2329 kg m^{-3}
- **Crystal Lattice** : cubic, diamant
- **Melting Point** : 1683 K
- **Boiling Point** : 2628 K
- **Electrical Conductivity [298K]** : $1000 \text{ Ohm}^{-1} \text{ m}^{-1}$
- **Thermal Conductivity [300K]** : $148 \text{ W m}^{-1} \text{ K}^{-1}$
- **Heat of:**
 - *Fusion*: 39.6 kJ mol^{-1}
 - *Vaporization*: $383.3 \text{ kJ mol}^{-1}$
 - *Atomization*: 452 kJ mol^{-1}

HISTORY:

Elemental silicon was prepared for the first time by Berzelius, in 1823, who placed silicon tetrafluoride in the presence of warm potassium. However, it was thought that Gay-Lussac and Thenard had already tried to obtain the amorphous silicon by the same method, in 1809. The substance obtained by Berzelius was a purer product as a result of exhausting filtering. Berzelius prepared silicon from the reaction of potassium fluorsilicates with potassium.

In its crystalline form, silicon was first prepared by Deville, in 1854, through the electrolysis of impure sodium-aluminum chloride with about 10% of silicon. At the beginning of the 20th century (1907), Potter studied the interaction of silica with the carbon, which prepared the way to the process of obtaining silicon for commercial purposes during the whole century.

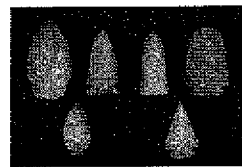


Jons Jacob Berzelius

SOURCE:

Silicon makes up 25.7% of the earth's crust by mass and is the second most abundant element. It does not occur free in nature but occurs chiefly as the oxide and as silicates. The oxide includes sand, quartz, rock crystal, amethyst, agate, flint and opal. The silicate form includes asbestos, granite hornblende, feldspar, clay and mica.

Silicon is prepared commercially by electrolysis with carbon electrodes of a mixture of silica and carbon. Silicon is used extensively in solid-state devices and for this hyper pure silicon is required. This is prepared by thermal decomposition of ultra-pure trichlorosilane.



OCCURRENCE:

Silicon occurs in nature combined with oxygen, in the form of silicon dioxide, and with oxygen and several metals, in the silicate form, but is never found isolated. As a whole, the silicates and the silica represent 60% of the terrestrial crust. The SiO_4 is the primary structural unit of all these substances.

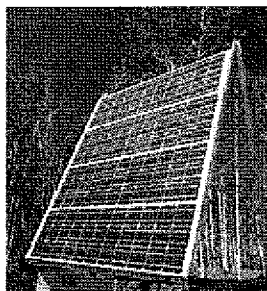
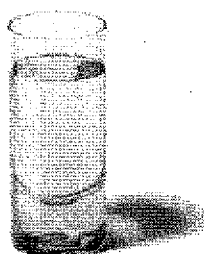
The silicon dioxide, commonly called silica, is one of the most important silicon compounds occurring in nature. This compound occurs in three different crystalline forms: quartz, tridymite and cristobalite. These last two can only be found in volcanic rocks and do not have industrial applications. During the test of the first atomic bomb in New Mexico other silicon crystalline form appeared: the keatite. The quartz is very common and it can be found in granite, sand and sandstone. It is a piezoelectric substance used to stabilize amplifier circuits, to measure high electrical potentials or to measure high instantaneous pressures. There are sufficiently big and pure quartz crystals in nature to be used for optical purposes.

There are also several forms of amorphous silica with water, such as the opal or the *geyserites*. From these, the black opal of Australia stands out, being one of the most valuable precious stones.

USES:

Silicon is one of the most useful elements to mankind. Sand and clay, which both contain silicon, are used to make concrete and cement. Sand is also the principal ingredient of glass, which has thousands of uses. Silicon is a component of steel, and silicon carbides are important abrasives and also used in lasers. Silicon is present in pottery, in enamels, and in high-temperature materials.

Increasing use for silicon is now being found in micro-electronic devices. The silicon is usually doped with boron, gallium, phosphorus or arsenic for use in transistors, solar cells, rectifiers and other instruments.



BIOLOGICAL INFO:

Silica occurs in living organisms. It is possible that silicon may have played an important, perhaps even necessary role, in the origin of life on the earth. The pattern of deposition of silica in plants is biologically specific and it is possible to identify plants by microscopic examination of silica particles. In some cases, silica appears to be a factor in the resistance that plants offer to diseases and insects.

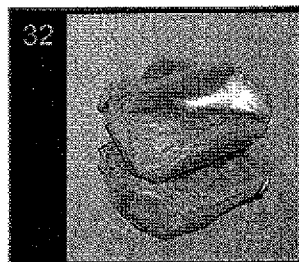
Human tissues often contain from 6 to 90 mg of silica per 100 grams of dry tissues. Lung tissue may vary from 10 mg in infancy to as much as 2000 mg per 100 grams in old age. Miners, stonecutters, potters and others engaged in work where siliceous dust is breathed in large amounts often develop a serious lung disease called silicosis.

GENERAL INFO:

Amorphous silicon is a brown powder, and crystalline silicon is a gray color with a metallic luster. Silicon is relatively inert.

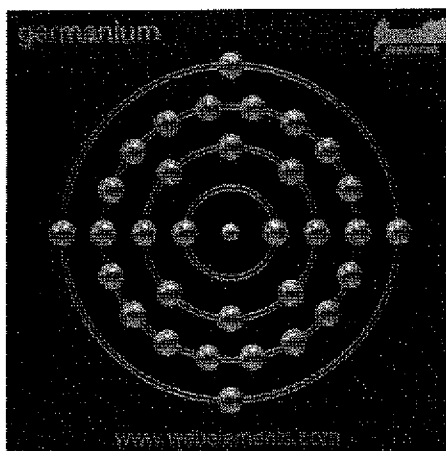
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Germanium



THE BASICS:

- **Name:** Germanium
- **Atomic Number:** 32
- **Chemical Symbol:** Ge
- **Electronic Configuration:** $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10} 4p^2$

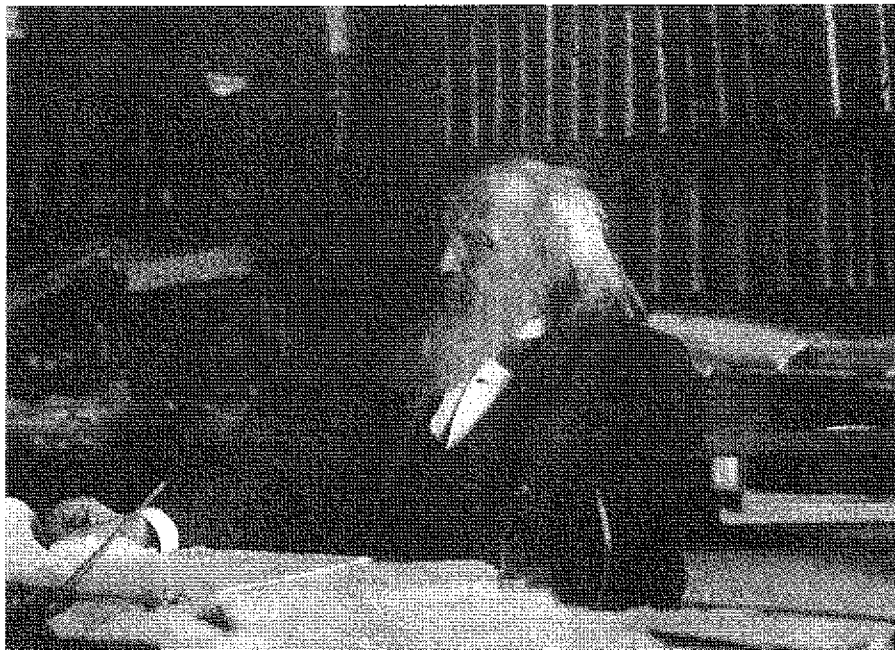


- **Abundance:**
 - *Earth:* 1.8 ppm
 - *Solar System:* 3160 (rel. to $[H]=1 \times 10^{12}$)
- **Atomic Mass:** 72.61
- **Electronegativity:**
 - *Pauling:* 2.01
 - *Allred:* 2.02
 - *Absolute:* 4.6 eV
- **Electron Affinity:** 116 kJ mol^{-1}
- **Polarizability:** 6.1 \AA^3
- **Radius:**
 - Ge^{2+} : 90 pm
 - *Atomic:* 122.5 pm
 - *Covalent:* 122 pm
 - Ge^{4-} : 272 pm
- **Common Ions :** Ge^{2+} , Ge^{4-}
- **Most Common Elementary Substance :** Ge
- **Elementary Substance Class :** Semi-metal
- **Origin :** Natural
- **Physical State :** Solid

- **Density [298K]** : 5323 kg m^{-3}
- **Crystal Lattice** : cubic, diamond
- **Melting Point** : 1211 K
- **Boiling Point** : 3103 K
- **Electrical Conductivity [298K]** : $217.39 \text{ Ohm}^{-1} \text{ m}^{-1}$
- **Thermal Conductivity [300K]** : $59.9 \text{ W m}^{-1} \text{ K}^{-1}$
- **Heat of:**
 - *Fusion*: 34.7 kJ mol^{-1}
 - *Vaporization*: $334.3 \text{ kJ mol}^{-1}$
 - *Atomization*: 377 kJ mol^{-1}

HISTORY:

In his report on "The Periodic Law of the Chemical Elements", Mendeleev predicted the existence of several unknown elements. Among them was one which was supposed to be just below silicon and, for that reason, he called it eka-silicon. Mendeleev studied several minerals, although unsuccessfully, seeking for that new element 32.



Dmitry Mendeleev

In the summer of 1885, a new mineral, argyrodite, was found in the Himmelsfurst mine (Freiberg, Germany). The exact composition of this ore was unknown, so C. Winkler, a Freiberg's chemist, proposed its study. He found silver, sulfur, iron oxide, zinc and an element unknown till that time (eka-silicon). In February of 1886, Winkler was sure of the discovery of this new element that he named germanium in honor of his fatherland.

SOURCE:

Germanium is found in small quantities in the minerals, germanite and argyrodite. It is also present in zinc ores. Commercial production of germanium is by processing zinc smelter flue dust. It can also be recovered from the by-products of coal combustion, ensuring a copious future supply.

OCCURRENCE:

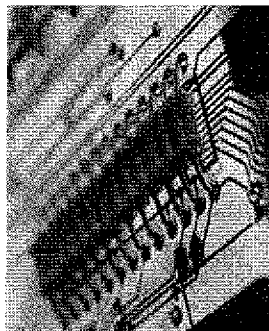
Germanium is not very abundant, so that we can even say that it is a rare element. Its principal

compounds are argyrodite ($4\text{Ag}_2\text{S} \cdot \text{GeS}_2$), germanite ($7\text{CuS} \cdot \text{FeS} \cdot \text{GeS}_2$), canfieldite ($4\text{Ag}_2\text{S} \cdot (\text{Sn} \cdot \text{Ge})\text{S}_2$) and renierite ($(\text{Cu}, \text{Ge}, \text{Fe}, \text{Zn}, \text{As})\text{S}$). Of these, only the germanite deposits in Tsumeb (Southwest Africa) and renierite deposits in Katanga (Congo) are of major industrial significance. Trace amounts of germanium (up to 0.3%) are reported in many sulfide and oxide minerals and coal.

USES:

Germanium is extensively used in electronics. Added to beryllium, it leads to increasing ductility, and added to copper, it improves chemical resistivity. It is also used in several brazing alloys. Germanium is an important part of industrial glasses because of its infrared transmission and high refractive index.

Germanium has played the most important role in the development of solid state electronics beginning with the discovery of the transistor in 1948. It is one of the most studied and best understood of all elements. The discovery of the transistor action pointed the way to numerous solid state electronics phenomena, forming the basis of a new science and technology of solid state electronics. Cyclotron resonance, a means for determining the effective mass of charge carriers, was first observed in germanium single crystals. A variety of optical and magneto-optical measurements allowed for determining of fundamental parameters necessary for understanding the band structure of solids.



BIOLOGICAL ROLE:

Germanium has no known biological role. It is non-toxic. Certain germanium compounds have low mammalian toxicity but marked activity against some bacteria, which has stimulated interest in their use in pharmaceutical products.

Structural and electrical properties of tantalum nitride thin films fabricated by using reactive radio frequency magnetron sputtering

H. B. Nie, S. Y. Xu, S. J. Wang, L. P. You, Z. Yang^{a)}, C. K. Ong and J. Li

Center for Superconducting and Magnetic Materials, Institute of Engineering Science and Department of Physics, National University of Singapore, Lower Kent Ridge Road, Singapore 119260

a) Permanent address: Research Institute of Magnetic Materials, Lanzhou University, Lanzhou 730000, P. R. China.

T. Y. F. Liew

Data Storage Institute, DSI Building, 5, Engineering Drive 1, Singapore 117608

Abstract

Ta-N thin film is an attractive interlayer as well as a diffusion barrier layer in $[\text{Fe-N/Ta-N}]_n$ multilayers for the application as potential write head materials in high density magnetic recording. We synthesized two series of Ta-N films on glass and Si substrates by using reactive radio frequency sputtering under 5 mtorr Ar/N_2 processing pressure with varied N_2 partial pressure, and carried out systematical characterization analyses of the films. We observed clear changes of phases in the films from metallic *bcc* Ta to a mixture of *bcc* Ta(N) and hexagonal Ta_2N , then sequentially to *fcc* TaN and a mixture of TaN with N-rich phases when N_2 partial pressure increased from 0.0% to 30%. The changes were associated with changes in the grain shapes as well as in the preferred crystalline orientation of the films from *bcc* Ta [100] to [110], then to random and finally to *fcc* TaN [111], correspondingly. It was also associated with a change in film resistivity from metallic to semiconductor-like behavior in the range of 77K-295K. The films showed typical polycrystalline textured structure with small, crystallized domains and irregular grain shapes. Clear preferred (111) stacks parallel to the substrate surface with embedded amorphous regions were observed in the film. TaN film with [111] preferred orientation and a resistivity of $6.0 \text{ m}\Omega\cdot\text{cm}$ was obtained at 25% N_2 partial pressure, which may be suitable for the interlayer in $[\text{Fe-N/Ta-N}]_n$ multilayers.

PACS: 81.05.Je (Ceramic and refractories); 81.15.Cd (Deposition by sputtering); 68.55.-a (Thin film structure and morphology); 68.35.Rh (Phase transition and critical phenomena)

1. Introduction

Recently exciting breakthroughs in processing magnetic thin film media for ultrahigh recording density on rigid disk over $25\text{-}35 \text{ Gbit/in}^2$ have been made by Seagate and IBM [1-2]. This area density is by far beyond the "theoretical limit" i.e. 10 Gbit/in^2 which was widely accepted a few years ago. With this achievement, to obtain a recording density of $40\text{-}100 \text{ Gbit/in}^2$ using magnetic media is not just a dream in the near future. Significant progresses have also been made in the new generation of read head by using various types of GMR (giant magnetoresistive) spin valve multilayers [3-6] that fulfill the challenging requirements of reading process at high speed/frequency on high recording density media.

However, the development of write head has not matched with the fast development of media and read head yet, and thus more intensive studies are expected in this area.

In order to obtain satisfactory overwrite performance of the recording process, the write head materials should inhabit superior properties such as very high saturation flux density B_s of around 20 kG, high frequency permeability μ' of order 10^3 at 10^{2-3} MHz, very low coercivity H_c (say, <1 Oe), thermal stability up to 400-500 °C and very small magnetostriction. One sort of the potential candidates for the new generation write head materials are the iron base thin films such as FeN, FeTaN and FeAlN [7-12]. To reduce the thermal noise induced by eddy current and to obtain excellent high frequency performance up to 10^{2-3} MHz, various $[\text{Fe}(\text{Ta}, \text{Al})\text{N}/\text{M}]_n$ multilayers have been synthesized and investigated, where M is representing for the interlayer, e.g., TaN, Ta, SiO_2 , Al_2O_3 , NiFe, CoZrRe, SiN, and AlN [12-22]. Among them, with TaN as interlayer, $[\text{FeTaN}/\text{TaN}]_n$ multilayers were demonstrated to have excellent magnetic properties at high frequency up to 100 MHz and high temperature stability up to 430 °C [12].

Ta-N is a chemically inert refractory compound. Here we use Ta-N to represent various phases of Ta-N system, such as β -Ta₂N, θ -TaN, η -TaN, δ -TaN_{1-x}, Ta₅N₆, Ta₄N₅, Ta₃N₅, etc. [23-24]. Before Ta-N thin film is used as an interlayer in soft magnetic multilayers, it has already been applied as a stable thin film resistor of low temperature coefficient of resistivity [25-27], an excellent diffusion barrier between silicon and metal overlayers of Ni, Al and Cu [28-33], etc. For different applications, Ta-N thin films have been successfully fabricated by using several kinds of techniques such as reactive sputtering [27-29, 31, 34-39], metalorganic chemical vapor deposition (MOCVD) [40], ion beam assisted deposition (IBAD) [41-42] and electron-beam evaporation [43]. However, due to the complex phase diagram of Ta-N system, the experimental results of different research groups are not consistent satisfactorily with each other, and the growth mechanism of Ta-N film has not been fully understood yet. We believe that a better understanding of the growth mechanism of Ta-N thin films will shed light on the synthesizing of excellent TaN interlayer films in $[\text{Fe}(\text{Ta}, \text{Al})\text{N}/\text{TaN}]_n$ multilayers as qualified write head materials for recording density of 20-40 Gbit/in² or higher. For this purpose, it is required that the TaN interlayer have relatively high resistivity, smooth surface, good diffusion barrier capability, homogeneous thickness (e.g. 3 nm), and a stable reproducibility. All these add up to a challenging task.

In this work, radio frequency (rf) reactive magnetron sputtering technique was applied to prepare the Ta-N thin films. The sputtering process is now the most main technique for processing recording media on hard disk and for GMR/spin valve materials. It has an excellent reproducibility and a large efficient deposition area. We also fabricated Fe(Ta)N thin films with the same technique. By this way, we will be able to synthesize $[\text{Fe}(\text{Ta})\text{N}/\text{TaN}]_n$ *in situ* after we have individually and systematically investigated Fe(Ta)N and Ta-N films on their morphological, structural and electrical properties, as well as on the correlation between the deposition parameters and the quality of as-deposited films.

2. Experimental

The Ta-N thin films were fabricated by using reactive rf (13.56MHz) magnetron sputtering deposition technique on a Denton Vacuum Discovery-18 Deposition System with a 3-inch-diameter tantalum target (purity 99.95%). Both 1"x1" amorphous glass and 10 mm x 10 mm (100) Si wafers were used as substrates. The substrates were cleaned prior to the deposition with in a sequence of acetone, distilled water and ethanol in an ultrasonic bath

for 15, 5 and 15 minutes, respectively. For each deposition, 2-3 pieces of glass substrates and 6-8 pieces of Si substrates were mounted on a copper substrate stage at a distance of 8-14 cm from the target surface. During deposition, the substrate stage was rotated at 9 RPM to obtain homogeneous film quality and thickness. The system was first pumped to 8×10^{-7} torr in about 5 hours. Then a mixture of pure Ar/N₂ gases (purity 99.9995%) was induced in the deposition chamber by using mass flow controllers. The total processing ambient gas pressure was kept at 5.0 mtorr for all the films, while the N₂ partial pressure was varied from 0.0%, to 2.5%, 5.0%, 7.5%, 10%, 15%, 20%, 25%, up to 30% for a series of Ta/Ta-N films. The rf power was kept at 200 W, corresponding to a power density of 4.3 W/cm² on the target surface. Each film was deposited for 60 minutes. Without undergoing any post-annealing process, the as-deposited films were directly measured by using various characterization techniques including X-ray diffraction (XRD), atomic force microscopy (AFM), surface profiler, high-resolution electron microscopy (HREM), four-probe method, etc.

3. Results and discussion

3.1 Thickness, deposition rate

Measured by using an Alpha-Step 500 Surface Profiler, the thickness of the films grown on glass substrates was found varying in 403-703 nm, corresponding to a deposition rate of 6.7-11.7 nm/min, almost linearly decreasing with the increase of N₂ partial pressure with a gradient of -0.17 nm/min per 1.0 % of N₂ partial pressure, as shown in Table 1 and Fig. 1. The decrease of deposition rate could be attributed to a decreasing number of opening sites on the Ta target surface for sputtering, for many sites of the target surface are occupied by nitrogen atom, N₂, or Ta-N compounds when N₂ partial pressure increases [39, 44]. However, the linear dependence of growth rate on N₂ partial pressure we observed is quite different from that in previous reports [34, 39]. As will be discussed in the following sections, difference is also found in changes of phases in the films. It indicates that, even under same N₂ partial pressure, the growth mechanism of the Ta-N films depends greatly on the deposition system and processing parameters such as rf power density, total ambient gas pressure and target-to-substrate distance.

3.2 Phases, crystalline structures and hardness

The crystalline structures of the as-deposited films were measured by using θ -2 θ XRD with a Cu K α source working as 30 kV and 20 mA. Fig. 2a shows the XRD patterns of Ta/Ta-N films deposited on glass substrate at different N₂ partial pressures. The pure Ta film (#1) shows two very sharp (200) and (400) peaks of the *bcc* (body-centered cubic) Ta structure. When N₂ was induced in the deposition process at a low partial pressure, *bcc* crystalline structure was found still dominating in the Ta(N) films, where Ta(N) representing that part of nitrogen atoms have taken the interstitial position of the *bcc* Ta lattice. However, as shown in curve #2 and #3, the closely-packed (110) faces of *bcc* Ta(N) shows much higher XRD intensity than the other existing peak, (211) of *bcc* Ta(N). Other orientation of the crystalline grains may also exist, but their XRD intensities are too small to be identified. With the increase of N₂ partial pressure from 2.5% to 5.0%, the (110) peak becomes lower; broader, and shifts towards the low angle direction, corresponding to an expansion of the *bcc* Ta(N) lattice constant from 3.343 Å to 3.369 Å. According to some previous results, a 5% N₂ partial pressure in the deposition process may already result in a atomic concentration of 40-50% of nitrogen in the as-deposited Ta(N) films [34, 39]. Thus the as-indexed (110) peaks of #2 and #3 sample in Fig. 2 in fact may consist of (110) peak of the

bcc Ta(N) and (101) peak of hexagonal Ta₂N, as their corresponding lattice distance, 2.338 Å and 2.323 Å, respectively, are quite close to each other.

When the N₂ partial pressure is increased to 7.5% and above, the XRD patterns changes again. In curves #4-#7 for N₂ partial pressure of 7.5% to 20%, 5 clear peaks can be identified in each curve as (111), (200), (220), (311) and (222) of the *fcc* (face-centered cubic) TaN (also referred as δ -TaN_{1-x} [23]) phase. It means the film consists of polycrystalline TaN grains with random orientation. At N₂ partial pressure of 15%, the (200) peak appears much higher and sharper than the rest. In curves #7-#9, corresponding to N₂ partial pressures of 20%, 25% and 30%, respectively, the (111) peak becomes dominating, implying that the crystalline grains in the films are highly oriented along [111] direction. Here a transition from random orientation to [111] preferred orientation is observed. Although, at high N₂ partial pressure, N-rich phases e.g. Ta₃N₅, Ta₅N₆ may appear [34], here no signs of such phases in the XRD pattern (#7-#9) were observed. Nevertheless, as revealed from the resistivity measurement discussed later (see section 3.5), N-rich phase(s) should already exist in the film prepared under 25%, 30% N₂ partial pressures, which attribute to the steeply increased resistivity of the film (Fig. 7).

As the position shift of the (111) peaks in curve #4-#9 was noted, we carefully performed step scans for each sample and calculated their corresponding lattice constants. Here we suppose the lattices of the crystalline grains in these films keep their *fcc* structure. The results are shown in Fig. 3a. When N₂ partial pressure increases from 7.5% to 30%, the corresponding *fcc* lattice constant in the film increases by 1.4 % from 4.365 Å to 4.427 Å. Compared with the lattice constant of bulk *fcc* TaN, which is 4.336 Å [23], the relative increases of the lattice constant are 0.67 % and 2.1 % at N₂ partial pressures of 7.5% and 30%, respectively. Since Ta-N is a defect compound system where a wide atomic percentage range of N is allowed in its stable phases [23, 24], lattice distortions can be expected in each phase. The XRD patterns in Fig. 3a clearly show a trend of lattice cell expansion associated with the increase of N₂ partial pressure in deposition process. However, the lattices in film #4-#9 may not keep their perfect *fcc* structure, so that the values of lattice constant calculated in Table 1 and Fig. 3b are not absolutely true.

The side view of the [111] orientated TaN lattice consists sequent stacking layers of Ta and N atom [23]. With this [111] preferred orientation, the closest-packed faces {111} of the *fcc* TaN are parallel to the film plane, and the N atoms at vacancies or interstitial positions will help to prevent atoms from diffusing through the TaN layer, thus the film will show a best performance as a barrier layer.

To support the inferences from XRD patterns, we performed measurements using auger electron spectroscopy (AES) and derived the nitrogen concentration in the Ta-N films grown under varied N₂ partial pressure. Figure 4 shows the nitrogen concentration in Ta-N films as a function of N₂ partial pressure determined by auger electron spectroscopy (AES). The atomic concentration of nitrogen in the films increased steeply when processing N₂ partial pressure was increased from 0.0% to 10.0%, approaching 40-50 atm%. Then nitrogen concentration began to saturate, however, kept on increasing slowly when the processing N₂ partial pressure was further increased. This trend has been observed previous [34, 39]. It is consistent with the changes of phases in the films observed from XRD patterns, from *bcc* Ta(N) and hexagonal Ta₂N, to TaN (δ -TaN_{1-x}), and finally towards N-rich phases.

On the Si (100) substrates, we observed exactly the same trends of changes in the film structure as N₂ partial pressure increases. The XRD patterns are shown in Fig. 2b, and the

change of responding lattice constant is shown in Fig. 3b. They are very similar to those obtained from the films grown on glass substrate. The reason is that, since we fabricated the films at room temperature, both glass and Si substrates just serve as smooth and flat surface for the films and the inter diffusion between substrate and Ta-N film could be neglected. If the films are grown at high temperature, we may expect serious diffusion effect of Si into the film thus different structures of the as-deposited films on glass and Si substrates.

Two points should be mentioned here. Firstly, the XRD patterns (Fig. 2a, 2b) indicate that the films are not well crystallized. A considerable amount of amorphous Ta-N materials is expected in the film, where crystalline grains are embedded. This kind of structure is revealed in our TEM analysis. Secondly, under the given rf power, we note that the cubic TaN phase can be easily formed in the as-deposited film when suitable N_2 partial pressure is applied. In a bulk Ta-N system prepared by heating Ta in high pressure of N_2 , metastable cubic TaN can be obtained only at very high temperature, e.g., 1700 °C [45]. This implies that, in sputtering process, the energy needed for forming the cubic TaN phase could be obtained from the high energetic ions in the plasma generated by the rf or dc power [43].

In addition, the hardness of Ta-N films may be a key concern for certain application, and it also offers some indirect information on the film structure. Fig. 5 shows the results obtained from the Ta-N thin films grown on silicon, tested by the continuous stiffness measurement technique on a MTS Nanoindenter XP system with a Berkovich diamond tip. The indentation experiment was done at a constant strain rate to a depth of 350 nm. A series of 4 indentations were conducted on each sample and the results were averaged for each sample. With N_2 partial pressure increasing from 0.0% to 30.0%, the hardness varies between 15 GPa and 30 GPa. The highest value of hardness, 27.8 GPa, was observed in the film grown under N_2 partial pressure of 10.0%. The results are consistent with those reported by other researchers [46, 35].

3.3 *Surface morphology, grain size and roughness*

The surface morphologies of the films investigated by using AFM are consistent with the XRD results. AFM images were obtained on a Digital Instruments Nanoscope IIIa system with a Si_3N_4 cantilever operating under tapping mode. Typical AFM micrographs of the films on glass substrates are shown in Fig. 6. The grain shape shows a sequence of round, shuttle-like, and round again at N_2 partial pressures of 0.0%, 2.5% and 5.0%, 7.5% or higher, respectively. Obviously, the changes of the grain shape are correlated with the changes of phase in the films, i.e., from [100] oriented pure Ta film, to the mixture of [110] preferred Ta(N) and Ta_2N films, and finally to random oriented or [111] preferred TaN and N-rich Ta-N films, respectively, as we observed from the XRD analyses. At N_2 partial pressure of 7.5%, 10%, 15%, 20%, 25% and 30%, the average grain sizes are found to be around 38 nm, 32 nm, 40 nm, 51 nm, 44 nm and 36 nm, respectively. However, their root mean square roughness calculated from a $1\ \mu m \times 1\ \mu m$ area of the film does not change a lot and does not show a clear trend with the increases of film thickness, as shown in Fig. 7.

3.4 *HREM study and microstructure*

Fig. 8 shows TEM cross-section images of a Ta-N sample with thickness of 430 nm grown on (100) Si wafer under N_2 partial pressure of 25%. The film is quite uniform in thickness and has a smooth surface (Fig. 8a). At the Ta-N/Si interface, a thin layer of amorphous SiO_x with thickness of 1.5-2.0 nm can be seen (Fig. 8b). Compared to the perfect Si lattices at the left side of the interface, the Ta-N layer on the right side does not show lattice

structure as they are not epitaxial on the Si wafer. However, we observe textured structure in the Ta-N layer with clear stacks, though not perfect, parallel to the Si wafer surface, as shown in Fig. 9. Amorphous zones are also found in the Ta-N layer, which are embedded in the textured film. The average spacing of the stacks is 2.5-2.6 Å, consistent well with the TaN (111) spacing revealed in the XRD data of the film. It confirms that the only one preferred orientation of the film is [111] perpendicular to the substrate surface.

To reveal the grain size and the in-plane orientation of the crystalline structure of the film, we also investigated the plane-view of the sample. Fig. 10a is a TEM dark-field plane-view image of the sample, where clear grains with dimension of several tens of nm can be seen. However, these grains have irregular shapes. In each grain, we can observe many small, crystallized domains in the size of several nm, and probably amorphous materials between the crystallized domains. Its selected-area electron diffraction (SAED) pattern shows typical rings of polycrystalline structure of the film (Fig. 10b), indicating that the crystalline domains in the film are randomly oriented. This is further confirmed in the HRTEM images of the plane-view sample, which reveal local crystallized zones with sizes of a few nm to ten nm with varying spacing and orientation, as typically shown in Fig. 11. The TEM analyses show that, there is a preferred (111) stacking textured structure in the TaN film, which is parallel to the substrate surface. The crystallized domains in the film are small (a few to ten nm), and their in-plane orientations are random. In between the crystallized domains, there are amorphous materials. Although grain boundaries can be seen clearly, the grains do not have regular shapes.

3.5 Resistivity

The resistivity ρ of the as-deposited films (Fig. 12) was determined by using standard four-point method with a temperature controllable testing device for the range of 77K (in liquid nitrogen) to 295 K (room temperature). At room temperature, the resistivity of pure Ta film was measured to be 95 $\mu\Omega\cdot\text{cm}$. When N_2 partial pressure is 2.5% or 5.0%, the film still shows a metallic behavior, i.e., a decreasing resistivity with the decrease of temperature from 295K to 77K, as typically shown in Fig. 13. On the other hand, the resistivity increases when N_2 partial pressure is higher than 7.5% with a semiconductor-like behavior, i.e., decreasing with the decrease of temperature (Fig. 13). We therefore argue that, when prepared under 2.5% or 5.0% N_2 partial pressure, although there may be a considerable Ta_2N phases in the film, metallic Ta and Ta(N) still contribute greatly for the conductivity of the film, which results in a resistivity close to that of pure Ta film. But when N_2 partial pressure is close to 7.5%, the conducting property of the film changes characteristically. We can also tell this from the change of grain shapes from shuttle-like to round shape, as shown in Fig. 5. In the previous sections, we have discussed a clear change in phases in the films from a mixture of metallic *bcc* Ta(N) and hexagonal Ta_2N to *fcc* TaN when N_2 partial pressure was increased from 5.0% to 7.5%. Now we note that this change was also associated with a change in the temperature dependence of resistivity from metallic to semiconductor-like behavior. Between 5.0% and 7.5%, an optimum N_2 partial pressure should exist, where the resistivity of the film may almost keep constant under changing temperature. Such a film is an excellent candidate for the application in film resistor.

4. Conclusion

Reactive rf sputtering is an efficient technique for obtaining various Ta-N thin films with different phases. It is found that structural, morphological and electrical properties of the Ta-N films have a strong dependence on the N_2 partial pressure in the deposition process of

rf sputtering. In the as-deposited films grown on both glass and Si (100) substrates, clear changes in the dominating phases were observed from metallic *bcc* Ta to a mixture of *bcc* Ta(N) and hexagonal Ta₂N when a small amount of N₂ (2.5% partial pressure or less) was induced in the deposition process, and sequentially to *fcc* TaN when N₂ partial pressure was close to 7.5% or higher. These changes are associated with the changes of crystalline orientation (with respect to the normal of the substrate surface) in the films, from the [100] preferred orientation metallic *bcc* Ta to [110] in the mixture of *bcc* Ta(N) and hexagonal Ta₂N, then to random orientation of *fcc* TaN, and finally to [111] preferred orientation of a mixture of *fcc* TaN and N-rich Ta-N film, respectively. The second change was associated with a change in the temperature dependence of the film resistivity from metallic to semiconductor-like behavior in the range of 77K-295K. Hardness of the films varied between 15 GPa and 30 GPa, peaked at 27.8 GPa in the film grown at N₂ partial pressure of 10.0%.

The general structure of the samples deposited under high N₂ partial pressure was found partially textured, with small crystalline domains in a few nm to tens of nm together with amorphous regions. They showed characteristic rings of polycrystalline structure in their plane-view electron diffraction patterns, and irregular grain shapes in the TEM dark-field images. In the TaN films grown under 25% and 30% N₂ partial pressure, a preferred (111) stacking lattices parallel to the substrate surface were clearly observed in the cross-section HREM images.

The room temperature resistivity of the films increases with the increase of N₂ partial pressure, reaches a value of around 6.0 mΩ·cm at 25% N₂ partial pressure and steeply increases to 14.8 mΩ·cm at 30% N₂ partial pressure. The deposition rate is found almost linearly decrease as the N₂ partial pressure increases, with a gradient of -0.17 nm/min per 1.0 % of N₂ partial pressure. However, the surface roughness of the films grown on both glass and (100) Si substrates is not sensitive with the change of N₂ partial pressure and always keeps at around 3-5 nm under high deposition rate (6.7-11.2nm/min) with a film thickness up to 673 nm.

We may conclude that, for the application of [Fe(Ta, Al)N/TaN]_n multilayers, a N₂ partial pressure around 25 % is suitable for the fabrication of Ta-N interlayer, which inhabits mainly TaN phase, a relatively high resistivity (6.0 mΩ·cm) and preferred close-packed (111) faces along the substrate plane. These characteristics will enable the film to have a low eddy-current-induced loss at high frequency and serve efficiently as barrier layer in the [Fe(Ta, Al)N/TaN]_n multilayers. As a result, the multilayers are expected to have excellent high frequency performance when used as write head materials. Our further work will be focused on finding the optimum process parameters for the TaN with film a thickness of 3-5 nm and a roughness < 0.3 nm. To achieve a low deposition rate (e.g., < 1 nm/min) could be one of the approaches.

Acknowledgement

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Table 1 List of the thickness, deposition rate, average grain size, root mean square roughness (Rq), the interplanar spacing of the (111) planes $d_{(111)}$, lattice constant a and resistivity ρ of rf sputtered Ta-N thin films grown on glass substrate under 5 mtorr Ar/N₂ processing pressure with varied N₂ partial pressure.

P _N (%)	Film thickness (nm)	Deposition rate (nm/min)	Average grain size (nm)	Roughness R _q (nm)	d ₍₁₁₁₎ (Å)	Lattice constant a (Å)	Resistivity ρ (mΩ•cm)
0.0	703	11.7	46	3.4			0.095
2.5	673	11.2	68	3.7		3.343	0.116
5.0	653	10.9	59	3.2		3.369	0.254
7.5	619	10.3	38	3.5	2.520	4.365	0.426
10	583	9.8	32	3.5	2.529	4.380	0.702
15	543	9.1	40	3.7	2.532	4.385	2.70
20	505	8.4	51	4.5	2.540	4.399	2.81
25	448	7.5	44	4.6	2.553	4.422	5.93
30	403	6.7	36	3.4	2.556	4.427	14.8

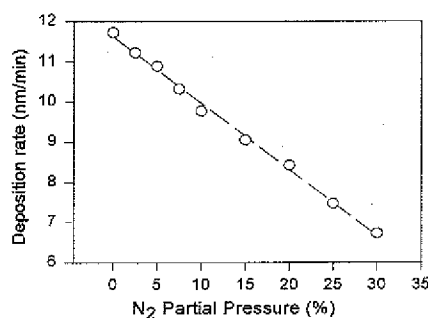


Fig. 1 Deposition rate of various Ta-N thin films grown on glass substrates vs. N₂ partial pressure shows a almost linear trend with a gradient of around -0.17 nm/min per 1.0 % of N₂ partial pressure.

Figure 2 (a) XRD θ -2 θ patterns of the films grown on glass substrates under 5 mtorr N_2 /Ar processing gas with various N_2 partial pressure of 0.0% (#1), 2.5% (#2), 5.0% (#3), 7.5% (#4), 10% (#5), 15% (#6), 20% (#7), 25% (#8) and 30% (#9).

Figure 2 (b) XRD θ -2 θ patterns of the films grown on Si (100) substrates under 5 mtorr N_2 /Ar processing gas with various N_2 partial pressure of 0.0% (#1), 2.5% (#2), 5.0% (#3), 7.5% (#4), 10% (#5), 15% (#6), 20% (#7), 25% (#8) and 30% (#9).

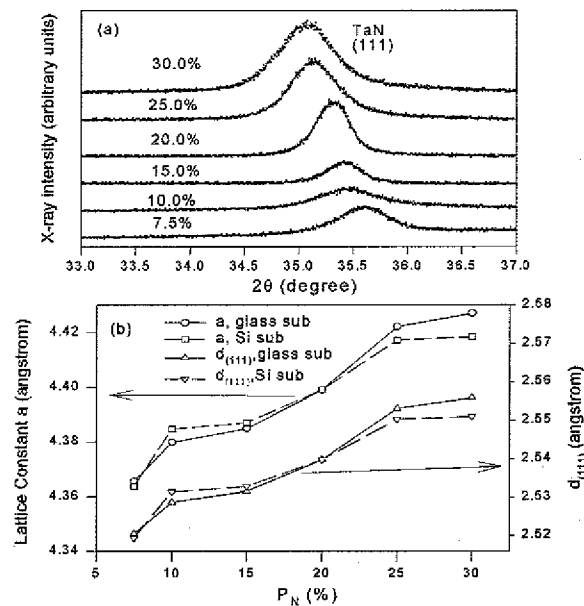


Figure 3 (a) The XRD step-scan patterns of the (111) peak of the curves #4-#9 in Fig. 3.2a, taken from films grown on glass substrates. The films grown on Si substrates show similar trends in their (111) step-scans. **(b)** Derived values of the interplanar spacing of the (111) planes $d_{(111)}$ and the corresponding lattice constant a of fcc TaN phase as a function of P_N in both the films on glass and Si (100) substrates, respectively.

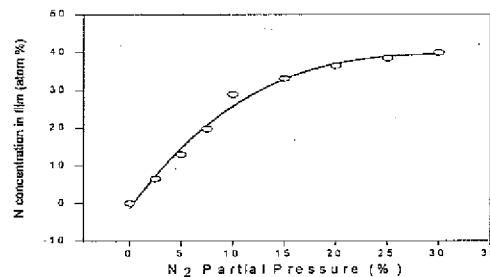


Figure 4 The nitrogen concentration in Ta-N films as a function of N_2 partial pressure determined by auger electron spectroscopy (AES).

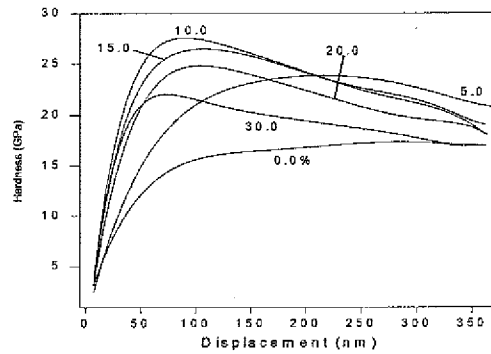


Figure 5 The hardness of the Ta-N thin films grown on silicon substrates under varied N_2 partial pressure. Curves shown here are averaged from 4 individual indentations for each sample. The value of hardness peaks in the sample grown under N_2 partial pressure of 10.0%.

Figure 6 The AFM tapping mode micrographs of the Ta-N films on glass substrates, with #1-#8 corresponding to processing N_2 partial pressure of (a) 0.0%, (b) 2.5%, (c) 5.0%, (d) 7.5%, (e) 10%, (f) 20%, (g) 25% and (h) 30%, respectively. Each image has the same size of $0.5 \mu m \times 0.5 \mu m$.

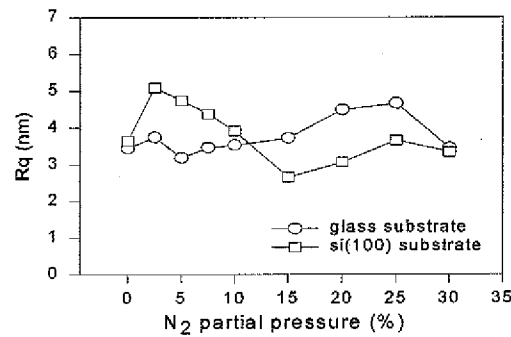


Figure 7 The average root mean square roughness (R_q) in an area of $1 \mu m \times 1 \mu m$ of the determined by using AFM vs. N_2 partial pressure.

Figure 8 TEM cross-section images of a TaN film with thickness of 430 nm grown on (100) Si wafer under N_2 partial pressure of 25%. (a) Low magnification view, it shows smooth film surface and homogeneous film thickness. (b) HRTEM image of the Ta-N/Si interface shows a thin layer of amorphous SiO_x .

Figure 9 HRTEM cross-section image of the Ta-N film grown on (100) Si wafer under N_2 partial pressure of 25% shows clear (111) stacks parallel to the substrate surface with spacing of 2.5-2.6 Å.

Figure 10 (a) A dark-field plane-view TEM image of the Ta-N film grown on (100) Si wafer under N_2 partial pressure of 25% shows irregular grains with small crystalline domains in the grains. (b) A TEM selected-area electron diffraction (SAED) pattern of the sample.

Figure 11 A typical plane-view HRTEM image of Ta-N film grown on (100) Si wafer under N_2 partial pressure of 25% shows various in-plane spacing of crystalline domains

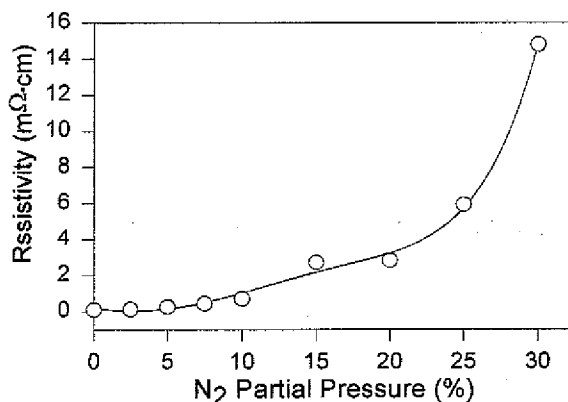


Figure 12 The values of room temperature resistivity of Ta-N films grown on glass substrates under various N_2 partial pressure show a steep increase when N_2 partial pressure of 25%-30%.

Figure 13 The temperature dependence of resistivity of the various Ta-N films grown on glass substrate under different N_2 partial pressure at 2.5%, 5.0%, 7.5%, 10%, 15.0% and 25.0 %. Note that the resistivity value has been united to $\rho(T)/\rho(295K)$, where $\rho(T)$ and $\rho(295K)$, are the resistivity at varied temperature T and 295 K, respectively.

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Condensed Matter > Materials Science

Title: Structural and electrical properties of tantalum nitride thin films fabricated by using reactive radio-frequency magnetron sputtering

Authors: [H.B. Nie](#), [S. Y. Xu](#), [S.J. Wang](#), [L.P. You](#), [Z. Yang](#), [C.K. Ong](#), [J. Li](#), [T. Y. F. Liew](#)
(Submitted on 29 May 2003 ([v1](#)), last revised 30 May 2003 (this version, [v2](#)))

Abstract: TaN thin film is an attractive interlayer as well as a diffusion barrier layer in [FeN/TaN](n) multilayers for the application as potential write-head materials in high-density magnetic recording. We synthesized two series of TaN films on glass and Si

substrates by using reactive radio-frequency sputtering under 5-mtorr Ar/N₂ processing pressure with varied N₂ partial pressure, and carried out systematic characterization analyses of the films. We observed clear changes of phases in the films from metallic bcc Ta to a mixture of bcc Ta(N) and hexagonal Ta₂N, then sequentially to fcc TaN and a mixture of TaN with N-rich phases when the N₂ partial pressure increased from 0.0% to 30%. The changes were associated with changes in the grain shapes as well as in the preferred crystalline orientation of the films from bcc Ta [100] to [110], then to random and finally to fcc TaN [111], correspondingly. They were also associated with a change in film resistivity from metallic to semiconductor-like behavior in the range of 77-295 K. The films showed a typical polycrystalline textured structure with small, crystallized domains and irregular grain shapes. Clear preferred (111) stacks parallel to the substrate surface with embedded amorphous regions were observed in the film. TaN film with [111]-preferred orientation and a resistivity of 6.0 mΩ cm was obtained at 25% N₂ partial pressure, which may be suitable for the interlayer in [FeN/TaN](n) multilayers.

Comments: 12 pages, 6 figures

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Characteristics of PECVD Grown Tungsten Nitride Films as Diffusion Barrier Layers for ULSI DRAM Applications

BYUNG LYUL PARK, DAE-HONG KO,* YOUNG SUN KIM,
JUNG MIN-HA, YOUNG WOOK PARK, SANG IN LEE,
HYEON-DEOK LEE, MYOUNG BUM LEE, U. IN CHUNG,
YOUNG BUM KOH and MOON YONG LEE

Semiconductor R&D Center, Samsung Electronics Co., LTD, San # 24,
Nongseo-Lee, Kiheung-Eup, Yongin-City, Kyungki-Do, 449-900, Korea

We have developed tungsten nitride (W-Nitride) films grown by plasma enhanced chemical vapor deposition (PECVD) for barrier material applications in ultra large scale integration DRAM devices. As-deposited W-Nitride films show an amorphous structure, which transforms into crystalline, β -W₂N and α -W phases upon annealing at 800°C. The resistivity of the as-deposited films grown at the NH₃/WF₆ gas flow ratio of 1 is about 160 $\mu\Omega$ -cm, which decreases to 50 $\mu\Omega$ -cm after an rapid thermal annealing treatment at 800°C. In the contact holes with the size of 0.35 μ m and aspect ratio of 3.5, the bottom step coverage of the tungsten nitride films is about 60%, which is about three times higher than that of collimated-TiN films. We obtained contact resistance and leakage current with the tungsten nitride barrier layer comparable to those with conventional collimated TiN films. The contact resistance and leakage current are stable upon thermal stressing at 450°C up to 48 h.

Key words: Diffusion barrier, plasma enhanced chemical vapor desposition (PECVD), tungsten nitride, ultra large scale integration (ULSI) DRAM

INTRODUCTION

The fabrication of ultra large scale integrated (ULSI) devices requires the development of new interconnection technologies for deep submicron processes. Particularly, the technologies of the diffusion barrier between the interconnection materials and the silicon in the contact hole, or between interconnection materials play a critical role with the continued scaling-down of devices. Among various materials, conventional titanium nitride films have been intensively investigated for the extended use in deep submicron regimes.¹ This technology, however, generates several issues in the process, or in film characteristics. The collimated sputtering process exhibits poor step coverage at the sidewall and bottom of the contact holes with reduced size and high aspect ratio, an the inherent problem of the sputtering processes.² The titanium nitride films grown by chemical vapor

deposition (CVD) methods have been suggested as alternatives owing to their step coverage higher than sputtering processes. Despite the significantly improved step-coverage, these processes bring with them challenges with respect to film characteristics and process characteristics, such as high resistivity, high impurity contents of the films or high processing temperature.^{3,4}

Tungsten nitride (W-Nitride) films grown by sputtering or CVD methods have been investigated for barrier material applications as an alternative to TiN films. Previous works showed that tungsten nitride films exhibit barrier characteristics comparable to those of TiN films and, thus, can be employed as barrier materials in contact holes.⁵ It was also demonstrated that tungsten nitride films exhibit compressive stress and resistivity values as low as 100 $\mu\Omega$ -cm.⁵

Therefore, considering basic film characteristics and physical properties, it is concluded that tungsten nitride is a good candidate as an alternative to conventional TiN films for contact barrier applications in deep sub-micron regimes.⁶⁻⁹ We have employed plasma

*Current Address: Department of Ceramic Engineering, Yonsei University, Seoul.

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GROUP IVA

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CARBON

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SILICON

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GERMANIUM

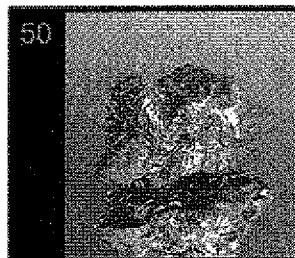
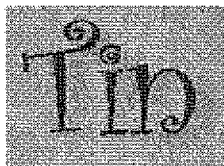
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TIN

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LEAD

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THE BASICS:

- Name: Tin
- Atomic Number: 50
- Chemical Symbol: Sn
- Electronic Configuration: $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10} 4p^6 5s^2 4d^{10} 5p^2$



- Abundance:
 - Earth: 2.2 ppm
 - Solar System: 100 (rel. to [H]) $= 1 \times 10^{12}$
- Atomic Mass: 118.71
- Electronegativity:
 - Pauling: 1.96
 - Allred: 1.72
 - Absolute: 4.3 eV
- Electron Affinity: 116 kJ mol^{-1}
- Polarizability: 7.7 \AA^3
- Radius:
 - Sn^{2+} : 93 pm
 - Sn^{4+} : 74 pm
 - Atomic: 140.5 pm
 - Covalent: 140 pm
 - Sn^{4-} : 294 pm
- Common Ions : Sn^{2+} , Sn^{4+} , Sn^{4-}
- Most Common Elementary Substance : Sn
- Elementary Substance Class : Metal

- **Origin** : Natural
- **Physical State** : Solid
- **Density [298K]** : 7310 kg m^{-3}
- **Crystal Lattice** : tetragonal
- **Melting Point** : 505 K
- **Boiling Point** : 2543 K
- **Electrical Conductivity [298K]** : $9.09 \times 10^6 \text{ Ohm}^{-1} \text{ m}^{-1}$
- **Thermal Conductivity [300K]** : $66.6 \text{ W m}^{-1} \text{ K}^{-1}$
- **Heat of:**
 - *Fusion*: 7.2 kJ mol^{-1}
 - *Vaporization*: $290.4 \text{ kJ mol}^{-1}$
 - *Atomization*: 302 kJ mol^{-1}

HISTORY:

Tin is one of the oldest metals known by man. There are domestic utensils and arms made of brass (copper with about 15% of tin), dating from 3500 B.C.. The Phoenicians had a very important role in the spread of brass utensils due to its commercial trades with Britain, Spain and the Middle East. Pliny referred, in 49 A.D., to the existence of tin and lead alloys, what we now know as solder, as well as recipients of tinned copper. Tinned iron was only developed in the 14th century in Bohemia, and tinned steel appeared only in the 17th century.

Originally confined to Britain and Spain, the tin extraction spread throughout to other countries of the Southern Asia and to Congo, Nigeria and Bolivia.

SOURCE:

Tin is found mainly in the ore cassiterite, which is found in Malaysia, Bolivia, Indonesia, Thailand and Nigeria. It is obtained commercially by reducing the ore with coal in a reverberatory furnace.

OCCURRENCE:

The major producers of tin are Malaysia, Thailand, Indonesia, Bolivia, Republic of Congo, Nigeria, and China. Although in a smaller scale there are also tin deposits in Australia, England, Burma, Japan, Canada, Portugal and Spain.

The only tin mineral with commercial importance is the cassiterite (SnO_2). This ore does not occur in mineral veins but in extensive alluvial deposits where the concentration does not surpass 4%.

USES:

Tin has many uses. Electro-plating is an important application of tin. It can be done through the electroplating of a small coat of tin around objects of steel, copper, aluminum etc. The tinned pieces have countless applications such as in kitchen utensils, spray recipients and shaving foam, ink cans, electronic components, integrated circuits, clips, pins and many other. Tinned objects can also be used with ornamental purposes. As a pure metal, it can still be used in storage tanks for pharmaceutical chemical solutions, in capacitors electrodes, fuse-wires, ammunitions, tinned iron sheets to protect victuals, sweets or tobacco etc. Some of the tin organic compounds have several application as fungicides and insecticides for the agriculture and still as wood, textile and paper preservers.

Alloys of tin are also important, such as soft solder, pewter, bronze and phosphor bronze. The most important tin salt used is tin (II) chloride which is used as a reducing agent and as a mordant. Tin salts sprayed onto glass are used to produce electrically conductive coatings. Most window glass is made by floating molten glass on molten tin to produce a flat surface. Recently, a tin-niobium alloy that is superconductive at very low temperatures has attracted interest.

The more important tin compound is the tin dioxide (SnO_2), used in electric resistors and dielectrics, and the tin monoxide that it is used in the production of tin salts for electroplating and as chemical reagents. The tin compounds that contain lead, barium, calcium and copper are

indispensable in the production of electric capacitors. The tin fluoride is used as additive in toothpastes.



BIOLOGICAL INFO:

Only a small tin amount is transmitted onto food from using of tin utensils. The maximum allowed amount is about 300 mg per kilogram, but in spite of this, higher concentrations are not generally harmful. Tin can be considered as a non toxicant element. However, some of its compounds have toxicant properties and should be handled with extreme care.

GENERAL INFO:

Tin is unreactive to water and oxygen, as it is protected by an oxide film. It dissolves in acids and bases. When heated in air tin forms tin (IV) oxide which is feebly acidic. Tin has two allotropic forms. On warming, gray tin, with a cubic structure, changes into white tin, the ordinary form of the metal.